Fate of Combat Nerve Injury

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Objective: Assess a cohort of combat related type III open tibia fractures with peripheral nerve injury to determine the injury mechanism and likelihood for recovery or improvement in nerve function.

Design: Retrospective study.

Setting: Three military medical centers.

Patients and Participants: Out of a study cohort of 213 type III open tibia fractures, 32 fractures (in 32 patients) with a total of 43 peripheral nerve injuries (peroneal or tibial) distal to the popliteal fossa met inclusion criteria and were available for follow up at an average of 20 months (range, 2 48 months).

Main Outcome Measurements: Clinical assessment of motor and sensory nerve improvement.

Results: There was a 22% incidence of peripheral nerve injury in the study cohort. At an average follow up of 20 months (range, 2 48 months), 89% of injured motor nerves were functional, whereas the injured sensory nerves had function in 93%. Fifty percent and 27% of motor and sensory injuries demonstrated improvement, respectively (P 0.043). With the numbers available, there was no difference in motor or sensory improvement based on mechanism of injury, fracture severity or location, soft tissue injury, or specific nerve injured. In the subset of patients with an initially impaired sensory examination, full improvement was related to fracture location (P 0.0164).

Conclusions: Type III open tibia fractures sustained in combat are associated with a 22% incidence of peripheral nerve injury, and the majority are due to multiple projectile penetrating injury. Despite the severe nature of these injuries, the vast majority of patients had a functional nerve status by an average of 2 year follow up. Based on these findings, discussions regarding limb salvage and amputation should not be overly influenced by the patient's peripheral nerve status.

Key Words: limb salvage, peripheral nerve injury, open tibia fracture, combat related

INTRODUCTION

One hallmark of the recent and continued US military conflicts in Afghanistan and Iraq has been the devastating extremity injuries sustained as a result of explosive mechanisms. Seventy-eight percent of all injuries are secondary to blast mechanisms, with extremity injuries making up more than half of all combat-related injuries.[1] Extremity injuries are not only the most common, they require the greatest amount of resources and cause the greatest disability.[2] Within this subset of extremity injuries, high-energy open tibia fractures remain one of the most challenging injuries to treat; multiple civilian series have demonstrated high complication rates and poor functional outcomes.[3–9] The mechanisms of injury in current combat operations differ from those causing fractures sustained in the civilian sector, where open tibia fractures most commonly result from blunt trauma secondary to falls or motor vehicle collisions.[10] Explosive mechanisms result in multiple projectile penetrating injury (MPPI) to the involved extremity, a mechanism that may be akin to that seen with shotgun injuries. Although the individual projectiles seen with shotgun injuries may travel at low velocity, the total kinetic energy imparted to the extremity is much greater than that seen with high-energy, single-missile injuries.[11,12]

Previous reports have demonstrated that peripheral nerve injuries are involved in as many as 30% of combat-related extremity injuries.[13] This is substantially higher than the rate in a recent cohort of 5000 civilian trauma patients, in which only 3% were found to sustain a peripheral nerve injury.[14] Originally classified by Seddon and later expanded by Sunderland, injured

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1. REPORT DATE **01 NOV 2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Fate of combat nerve injury**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Beltran M. J., Burns T. C., Eckel T. T., Potter B. K., Wenke J. C., Hsu J. R.,**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United Stataes Army Institute of Surgical Research, JBSA Fort Sam Houston, TX**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **UU**	18. NUMBER OF PAGES **6**	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**			

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

peripheral nerves may be stretched, contused, or transected.[15] Outcomes after overt nerve transection, despite surgical repair or grafting, have been consistently worse across multiple series when compared with severe neuropraxic injuries.[16–22]

Type III open tibia fractures may be associated with peripheral nerve injury. Before the Lower Extremity Assessment Project (LEAP study), many of these injuries, in particular those involving injury to the tibial nerve, were deemed unsalvageable and primary amputation was the recommended surgical intervention due to poor outcomes.[23,24] Although the results of the LEAP study challenged this indication by demonstrating tibial nerve recovery in a majority of cases,[25,26] little data currently exist to guide the treatment of type III open tibia fractures with high-energy nerve injuries such as those sustained in combat.

The purpose of this study was to retrospectively assess a cohort of combat-related type III open tibia fractures associated with peripheral nerve injury. We theorized that the majority of injuries would be associated with MPPI, consistent with published extremity injury reports from current US military conflicts,[1] and that many of the nerve injuries would demonstrate improvement in function, consistent with published results from the civilian LEAP cohort.

MATERIALS AND METHODS

Data Collection

This study was conducted under a protocol reviewed and approved by the US Army Medical Research and Material Command Institutional Review Board and in accordance with the approved protocol. We queried local trauma databases, operative logs, the Joint Theater Trauma Registry, and local inpatient and outpatient records to identify all military service members who sustained an open tibia fracture during combat operations between March 2003 and September 2007. Patients treated at 1 of our 3 institutions with a type III open tibia fracture and associated documented peripheral nerve injury distal to the level of the popliteal fossa were included in our study population. Exclusion criteria included the presence of a documented nerve injury proximal to the level of the popliteal fossa, spinal cord injury, injury involving only the sural or saphenous nerve, and acute amputation.

Motor and sensory functions of the tibial and peroneal nerves at initial evaluation and at last follow-up were recorded as either absent, altered, or normal. We defined motor nerve function based on the British Medical Research Council scale (Table 1). A score of 0 was defined as absent, 1–4 as altered, and a score of 5 as normal. Sensory function was defined subjectively according to the LEAP criteria.[26] Altered sensation was any sensation other than complete numbness, which was not expressed as normal. We considered a functional nerve status for motor strength to be any examination greater than 0/5, and for a functional sensory nerve status any examination other than complete numbness, indicating protective sensation.

The mechanism of injury was characterized as a blast mechanism (MPPI), gunshot wound (SPPI), or blunt trauma. Fracture location was recorded as either at the level of the proximal tibia, diaphysis, or distal tibia. Fracture severity was

TABLE 1. British Medical Research Council Grades

0	No contraction
1	Flicker or trace of contraction
2	Active movement with gravity eliminated
3	Active movement against gravity
4	Active movement against gravity and resistance
5	Normal power

Reproduced from British Medical Research Council. *Aids to the Investigation of Peripheral Nerve Injuries.* 2nd ed. London: Her Majesty's Stationery Office; 1943.

classified from admission anteroposterior and lateral radiographs according to the OTA classification system.[27] Injury to the soft tissue envelope was classified using the Gustilo and Anderson system.[28,29]

Statistics

Statistical analyses were performed to assess for differences in neurologic recovery with regard to injury mechanism, injury location, specific nerve injured, fracture severity, and severity of soft tissue injury. The collected data were then analyzed for statistical significance of observed differences in outcomes. Continuous variables and scores were compared via the Student t test for parametric data. Dichotomous variables were compared using the chi-square test or Fisher exact test, as appropriate. All reported P values are 2-tailed, with an $\alpha \leq 0.05$ determining statistical significance. Statistical analysis was performed with SAS 9.1 (Cary, NC).

RESULTS

We identified 213 high-energy Gustilo and Anderson type III open tibia fractures. Of this population, a cohort of 46 tibia fractures in 46 patients had a peripheral nerve injury distal to the popliteal fossa. Eight tibiae were acutely amputated within 2 weeks of injury for a nonreconstructable or dysvascular limb, and 6 tibia fractures had insufficient clinical follow-up. The remaining 32 tibia fractures with a combined 43 peripheral nerve injuries comprised our study population and were available for follow-up at an average of 20 months (range, 2–48 months). One soldier with only 2-month follow-up had full nerve recovery and was therefore included in our final analysis. The 14 tibiae (8 acute amputations and 6 lost to follow-up) are included in descriptive analysis below, but excluded from analysis of nerve improvement.

Patient Characteristics

The average patient age was 26 years (range, 19–43 years). There was a 22% (46/213) incidence of neurologic injury associated with severe combat-related open tibia fractures. Forty-eight percent (22/46) of tibia fractures were associated with an injury to the tibial nerve, whereas 38/46 (83%) were associated with an injury to the common peroneal nerve or 1 of its 2 branches. Twelve fractures (26%) had injury to both the tibial and peroneal nerve. The injuries were secondary to an MPPI in 37 (80%) and SPPI in 7 (16%), and 2 (4%) were caused by a motor vehicle accident. Ten fractures (22%) were of the proximal tibia, 26 (56%) of the mid-diaphysis, and 10 (22%) of the distal tibia. Gustilo and

Anderson type III-B fractures were present in 21 (46%) tibia, with IIIA and IIIC fractures accounting for 14 (30%) and 11 (24%), respectively. Ten fractures (22%) were classified as OTA type A fractures, 9 (20%) as type B, and 27 (58%) as type C. Three tibiae received a delayed amputation, 1 for chronic osteomyelitis and 2 for failed limb salvage due to severe chronic pain. None of these 3 patients had return of any motor or sensory function at the time of their amputations. Because of their extensive follow-up time, they are included below in an analysis of nerve improvement.

Motor Nerve Improvement

A motor deficit was present at presentation in 38 of the 43 injured nerves (88%) followed. Thirty-two percent (12/38) had absent function and 68% (26/38) had impaired function initially. At final follow-up, only 11% (4/38) had persistent absent function, whereas 53% (20/38) had impaired function and 37% (14/38) had return of normal function, indicating that 89.5% of tibia fractures with an initial motor nerve palsy had some nerve function. Of the nerves with initially absent motor function, 66% (8/12) experienced some recovery; 25% (3/12) returned to normal function (Table 2). Eleven of the 26 impaired nerves (42%) recovered to normal motor function (Table 3). There was no significant difference in the rate of improvement based on any of the studied variables.

Sensory Nerve Improvement

A sensory deficit was present at presentation in 41 of the 43 injured nerves (95%) followed. Of these, 10% (4/41) had absent function and 90% (37/41) had impaired function initially. At final follow-up, 25% (10/41) of nerves had normal sensory function and 68% (28/41) had impaired sensation, indicating that 93% of nerves with an initial sensory nerve palsy were functional. Eleven (27%) injured sensory nerves demonstrated improvement. One of the 4 nerves (25%) with absent function on initial examination had partial improvement and none had full improvement. Of the 4 nerves with absent initial sensation, 1 had a normal motor examination at presentation and never had sensory improvement, whereas 2 (50%) demonstrated neither motor nor sensory improvement; 1 of these nerves represented the only subject with an initially absent motor and sensory examination. Among those patients with absent initial sensory function (N = 4), there was no difference in improvement based on any of the studied variables (Table 2). Among the subset of patients who presented with an initially impaired examination, full improvement was related to fracture location. Nerves associated with middle third fractures fully improved in 18% (4/22) versus 71% (5/7) of those associated with distal tibia fractures (P = 0.0164) (Table 3). No differences were found when compared with proximal third tibia fractures.

Comparison of Motor and Sensory Improvement

Nineteen of 38 (50%) injured motor nerves demonstrated improvement compared with 11/41 (27%) sensory nerve injuries. This difference was statistically significant (P = 0.034). At final follow-up, nearly 90% of injured motor nerves and 93% of injured sensory nerves demonstrate either partial or full function on clinical examination.

DISCUSSION

The results reported herein suggest that the majority of nerve injuries associated with combat-related type III open tibia fractures can be expected to improve if given sufficient

TABLE 2. Final Clinical Examination in Patients Presenting With Initially Absent Nerve Functions

	Motor				Sensory			
	N	Absent, n (%)	Impaired, n (%)	Normal, n (%)	N	Absent, n (%)	Impaired, n (%)	Normal, n (%)
Mechanism of injury								
MPPI	11	3 (27)	5 (45)	3 (27)	2	1 (50)	1 (50)	
SPPI	1	1 (100)			2	2 (100)		
Fracture severity								
A	2	2 (100)			1	1 (100)		
B	4		4 (100)		1	1 (100)		
C	6	2 (33)	1 (17)	3 (50)	2	1 (50)	1 (50)	
Soft tissue injury (G/A)								
A	6	3 (50)		3 (50)	1	1 (100)		
B	6	1 (17)	5 (83)		3	2 (66)	1 (33)	
C								
Nerve injury								
Tibial	3	1 (33)	1 (33)	1 (33)	0			
Peroneal	9	3 (33)	4 (44)	2 (22)	4	3 (75)	1 (25)	
Fracture location								
Proximal	2	2 (100)			2	2 (100)		
Middle	7	2 (29)	5 (71)		1		1 (100)	
Distal	3			3 (100)	1	1 (100)		

TABLE 3. Final Clinical Examination in Patients Presenting With Initially Impaired Nerve Function

		Motor			Sensory	
	N	Impaired, n (%)	Normal, n (%)	N	Impaired, n (%)	Normal, n (%)
Mechanism of injury						
MPPI	20	12 (60)	8 (40)	32	24 (75)	8 (25)
SPPI	5	2 (40)	3 (60)	4	2 (50)	2 (50)
Blunt	1	1 (100)		1	1 (100)	
Fracture severity						
A	4	2 (50)	2 (50)	4	3 (75)	1 (25)
B	7	5 (71)	2 (29)	10	9 (90)	1 (10)
C	15	8 (53)	7 (47)	23	15 (65)	8 (35)
Soft tissue injury (G/A)						
A	8	4 (50)	4 (50)	13	8 (62)	5 (38)
B	14	11 (79)	3 (21)	20	17 (85)	3 (15)
C	4		4 (100)	4	2 (50)	2 (50)
Nerve injury						
Tibial	7	5 (71)	2 (29)	12	8 (67)	4 (33)
Peroneal	19	10 (53)	9 (47)	25	19 (76)	6 (24)
Fracture location						
Proximal	6	3 (50)	3 (50)	8	7 (88)	1 (12)
Middle	17	11 (65)	6 (35)	22	18 (82)	4 (18)
Distal	3	1 (33)	2 (66)	7	2 (29)	5 (71)

time for recovery. Also, consistent with previous reports from the present US military conflicts, the majority of injuries were associated with MPPI compared to SPPI.[1,30] Because few patients were available for study who had sustained injury due to SPPI, comparative analysis based on mechanism of injury was limited. Our series reveals a neurologic injury rate of 22% associated with combat-related high-energy open tibia fractures, which is similar to a rate reported in a previous combat injury series.[13] Furthermore, this study also identifies motor injuries as being more likely to improve than sensory injuries. When faced with a motor nerve injury, our data indicate that improvement can be expected half of the time, compared with approximately one-quarter of the time for a sensory deficit.

In the present study, improvement of motor and sensory nerve injuries with initial absent function was not related to any of the studied variables. Among those nerves with an initially impaired sensory examination, improvement to full function was related only to fracture location. As expected, distal sensory nerve injuries were more likely to improve than more proximal injuries. We determined that 93% of sensory nerve injuries had some function at final follow-up, with 27% demonstrating improvement and 25% having a normal sensory examination. Our numbers are similar to a cohort of patients from the LEAP study with initially absent plantar sensation. In that study, 14/15 patients (93%) had some return of function, with 10/15 (67%) having complete return of sensation.[24] Although our study population included mainly peroneal nerve injuries and not tibial nerve injuries as studied in the LEAP group, the results of both suggest that at least

partial lower extremity sensation (ie, protective sensation) can be expected to return in most cases if nerves are not overtly transected and if given an adequate amount of time for recovery.

Furthermore, recent reports from the military regarding rehabilitation of limb salvage patients with nerve and muscle deficits indicate that many patients are able to return to physical activities, even running, with the of use Return to Run Clinical Pathway.[31] Furthermore, early studies on the Intrepid Dynamic Exoskeletal Orthosis are promising, even in patients complicated by the presence of a foot drop (0/5 motor strength to the peroneal nerve), allowing them to resume athletic activities; some soldiers have even redeployed with combat units.[32]

The largest series of combat-related nerve injuries remains the work of Dr. George Omer Jr. at the Brooke Army Medical Center. He reported on nerve deficits secondary to upper extremity missile injury during the

FIGURE 1. A, Typical limb appearance associated with MPPI. Note the extensive and severe soft tissue loss and wide fragmentation zone of injury. B, Appearance of a limb after SPPI. Although severe soft tissue loss is evident, scattered fragmentation wounds are not seen.
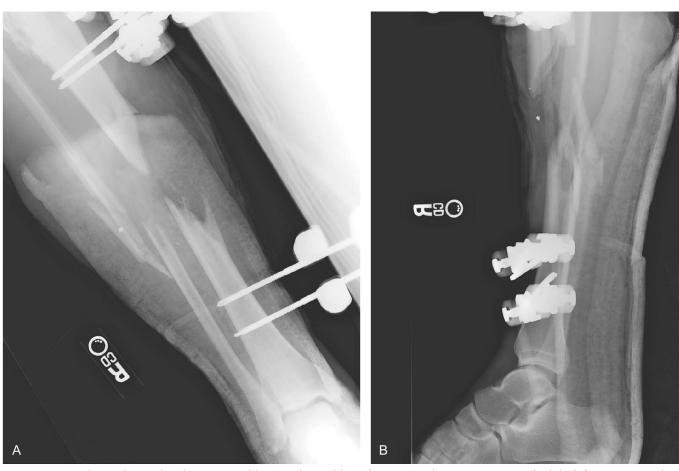
FIGURE 2. A and B, Radiographs of a 27-year-old active duty soldier who sustained a type III-B open tibial shaft fracture secondary to MPPI. Patient initially presented with absent motor and sensory function of peroneal nerve. At final follow-up (26 months), patient had improvement of both sensory and motor distributions, but did not recover normal function.

Vietnam War.[33] From a cohort of more than 900 nerve injuries, Omer determined that nerve recovery after gunshot wound can be expected 70% of the time when an injury is neuropraxic and 25% of the time when nerve repair is required after transection. He also found that neuropraxic recovery was seen between 3 and 9 months after gunshot injury. The applicability of these findings to the lower extremity remains limited, however. A recent report demonstrated lower rates of neurologic improvement among lower extremity nerves compared with those of the upper extremity when repair was performed.[34] Other previous reports of peripheral nerve injuries from the Balkan Conflicts of the 1990s have shown poor rates of motor and sensory recovery, specifically of the peroneal or tibial nerve, despite more aggressive attempts at repair.[19,20] Roganovic et al, in their series of more than 250 patients, demonstrated that results of peroneal or tibial nerve repair were universally poor in association with 3 factors: vascular injury, soft tissue defect, and underlying fracture. No patient with all 3 risk factors recovered peroneal nerve function, with only 14% of tibial nerves recovering.

Improvised explosive devices used by insurgents in current conflicts lead to high-energy, MPPI trauma through a wide pattern of fragmentation, an injury mechanism uncommon in the civilian world outside of close-range shotgun injuries (Figs. 1, 2). Shotgun injuries have been shown in multiple series to have higher rates of nerve transection and resultant poor recovery of function, despite attempts at repair.[12,35,36] The series of shotgun extremity injuries by Luce and Griffen[35] demonstrated that no greater than half of patients recovered neurologic function, irrespective of whether the nerve was transected or contused. Furthermore, their series of injuries all involved the upper extremity, where nerves have been shown to have improved recovery compared with the lower extremity.[35]

The current study is retrospective in nature and retains the associated weaknesses, potential biases, and limitations of all retrospective studies. Furthermore, the number of patients in this series is relatively small, which may prevent detection of a difference between groups that does exist. The patients who underwent acute amputation had more severe injuries deemed nonreconstructable; therefore, the nerve injuries associated with them may have been less likely to improve over time, introducing possible selection bias into our results. As a multicenter study, there were multiple surgeons involved, and each patient was managed according to the treating

surgeon's preference. Our follow-up averaged 20 months, indicating that some patients who had no recovery at last follow-up may recover some additional nerve function with time. We did not obtain follow-up electromyelography results on all patients, and the decision to explore nerves intra-operatively was not uniform and at the discretion of the operating surgeon. Therefore, we cannot definitively state which patients had neuropraxic injuries and who had complete or partial transections. In addition, because neurologic examinations at the time of initial evaluation and at follow-up were not standardized, we could only classify nerve function as absent, impaired, or normal and were not able to assess the time to initial or maximal improvement. Although this classification appears strong for assessing motor function, we found it relatively insensitive at assessing sensory function in a retrospective fashion. Furthermore, initial and final follow-up examinations were conducted by multiple, different reviewers, to include resident surgeons and staff surgeons; therefore, nerve assessment examinations were not standardized and often the initial and follow-up examinations were documented by different surgeons.

In conclusion, we have demonstrated that the majority of nerve injuries associated with combat-related type III open tibia fractures are secondary to MPPI, and this is consistent with previous extremity injury reports from the current conflicts. We have identified a 22% incidence of peripheral nerve injury associated with combat-related type III open tibia fractures. Despite the severe nature of bone and soft tissue injuries seen in these injuries, approximately 90% of open tibia fractures can be expected to have useful motor and sensory nerve function at an average of 20 months after injury. Motor nerve injuries can be expected to improve 50% of the time compared with 27% for sensory nerve injuries in these patients. Moreover, our results echo the findings of the LEAP study in demonstrating that initial motor and sensory examinations are often not predictive of final function. Using the initial neurologic examination in recommending for initial limb salvage versus amputation may therefore not be warranted.

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